"Fractal Pre-Structured" Building for (Temporary) Housing

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***Abstract*— How can we express today, in contemporary architecture, the geometrical-compositive possibilities of a formal conception based on modular pre-structured (prefabricated) units? And how can we compare this formal conception to the most topical needs, as those imposed by saving environmental resources or those, more dramatic, represented by the so-called mobile settlements: human flows in constant motion or the consequences of natural disasters? Is it possible find a solution, as response to these issues, which models the geometry of the temporary aggregate in relation to the shape of its basic modules? The needs of a historical analysis are rediscovered in the most topical architectural solutions for construction of temporary structures: Therefore the article suggests, a particular interpretation of fractal geometry, as the generating principle of constructive solutions that fully exploit the physical and formal properties of the elemental building units. The pre-structured cell becomes, today, the generative element of a n-dimensions building, that dilates more and more according to the intuition of Rudolph Kronenburg that identified the movable cell as "the brick" of the twentieth century. Under what kind of added values can we impose a constructive conception, in which the architectural form, looks like, scaled, the smallest element that constitutes it?**

***Index Terms*—fractal architecture, temporary housing.**

I. ACTUALITY OF TEMPORARY HOUSING

House and living individualize one of the most important topics in which the architectural research and the tradition of all peoples meet each other. Although with deep technical and cultural differences, the concept of dwelling is still connected to a condition of enduring existence or even permanent. More rarely we conceive, today, living as a condition linked to a very short period of time, and consequently we don't connect the constructive idea to a temporary living condition (even if the temporary housing accompanied human history since antiquity and even today, stands rooted, in few nomadic tribes around the world, as a form of mobility tied to a subsistence economy and also as a historical and cultural tradition). The reason for this "oversight" must be found, usually, considering that temporary housing, so-called nomadism, is associated to poor and backward ways of life. Nevertheless we believe that the topic of building the temporary housing, could be investigate as a very topical matter, in which architectural research, meets, interprets and resolves some real social needs of a different nature: -economic: the current crisis proposes, once again, the need to consider alternatives to traditional models of habitability, which meet new social demands (the sudden change of households, alternative solutions to property market often inaccessible, the need to support the movement of entire communities). -social: the age in which we live is characterized by a frenetic mobility, by an unceasing social stream, global scale, which requires a new conception of the idea of home. -safety: the inadequacy of traditional housing systems in emergency operations (natural disasters and conflicts). -aesthetics: a possible research related to an esthetic experimentation. "What is the best place for an instantaneous city, with its technical and figurative sets, to pose its "temporary foundations" more than those trans vague, that are those unmanned places on the outskirts of the permanent city? "[1]

II. FRACTAL GEOMETRY AS THE RATIO BETWEEN SIMPLE AND COMPLEX MODULAR STRUCTURES .

What kind of building geometry can interpret, at best, temporary architecture? And how can we update the tradition, interpreting in a modern constructive way, both its basic cell (the jointed tent of the Bedouin), and its aggregation? The answer may come from a design that defines in a geometric-constructive way, a bi-univocal tension between the single part (the unit) and the whole it has generated (through its combination). The first genetic point of this architecture is to define its basic unit (dwelling cell), as a theme and design challenge for lightness and portability, adaptability and expandability, modularity and reversibility. The second genetic point consists on the identification of some geometric aggregation that, moving from the unit dimension, can "grow" in space according to a logic, not only combinatorial but also incremental, scalable and changeable. General principles and criteria that can give

Figure 1a: nonlinear fractal geometry, Mendelbrot fractal. Figure 1b: linear fractal geometry, Sierpinski triangle. Figure 1c: linear fractal geometry, Sierpinski carpet.

form and expression to a renewed architecture that could be defined "of precariousness", made using a conceptual pre-structured technique of modular pre-fabricated materials. Essentially, an Architecture made by a multidimensional geometry: not only a formal geometry, but constructive; the

[1]W. Benjiamin, *L'opera d'arte nell'epoca della sua riproducibilità tecnica*, Einaudi, Torino, 2000.

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matrix of a civil construction that is entailed by the change of scale: from the elemental unit to its propagation. A geometric-constructive principle that we can certainly consider of fractal nature. "Fractal geometry is the formal study of self-similares structures and is at the conceptual core of understanding nature's complexity. The fractal dimension is a measure of the mixture of order and surprise in a structure."[1] Inherent in human nature, can be identified an use of fractal composition (unconscious) in the majority of urban and architectural achievements, even before it was officially defined as a geometrical typology. "(..) the origins of conscious fractal architecture cannot have occurred until after fractal geometry was formalized by Benoit Mandelbrot in the late 1970s even though Georg Cantor, Guiseppe Peano, David Hilbert, Helge von Koch, Waclaw Sierpinski, Gaston Julia and Felix Hausdorff had all studied aberrant or mathematically "monstrous" concepts that are clear precursors to fractal geometry."[2] The great buildings of the past and Vernacular Architecture all over the world show essential mathematical similarities, one of which is a fractal shape. Nikos Salingaros asserts : "(..) a building, or a city are subject to the same organizational laws of a biological organism or a complex computer program. The new architecture should depend on scientific rules rather than stylistic dictates. Using these rules, we can create new buildings. "[3]

III. THE PRE-STRUCTURED BUILDING OF "TEMPORARY ARCHITECTURE"

The proposed system can be defined by a following conceptual steps: - the single unit (the structural cell) as starting point - the system comes by a various aggregations of the number of the units (the material of the aggregation is the material of the cells, and the constructive law of the aggregation becomes pre-structured).

Figure 2a : shipping container used as dwelling. Figure 2b: Space Box, consists of a panel with high resistance to fire, the Resol, filled with foam to ensure a strong thermo-acoustic performance. Total thickness is about ten centimeters.

- the aggregation moves between A and B steps, adsuming various shapes and largeness, and and changing its scale and the scale of the units (the fractal dimension)

A. N=1: singularity

Parallelepiped. In the early eighties, the reuse of shipping containers, was one of the first experimentation of modular units (to create temporary houses).

Technology transfer and subsequent use as a building system in building construction was immediate and diffuse due to the ease to find the module and to its shape, that is suitable for interior design of a home. The development of the research was motivated by the need to find *"(..) the more efficient geometric shape and the most economical structural module, to enclose a generic space fit for various human needs."*[1]

These applications are still very topical for numerous possible compositions (including internal), that extend the area of applicability to buildings with a complex geometry. Due to its size could be composed in structures of considerable height and the steel walls could be removed or cut to create openings, windows or more space to join more elements. One extremely recent example: the new university campus "Citè a Docks" by Cattani Architects, in Le Havre France inaugurated in september 2010 (Fig. 4b). Cube. It finds important applications in many projects for temporary housing, especially in Northern Europe. As in the previous case, the form allows an easy transport of elements and their easy composition in complex structures. The cubic modules are usually brand new unit appositely designed to be assembled together in complex structures. For this reason they are made by very light material with, at the same time, a good resistance both to the structural loads and to the harsh climatic conditions. A mix of this properties is presented by the FRPs (fiber rynforced polymers) that, in fact, are largely used in this kind of applications. Curve geometries. These are cylindrical shells, semi-cylindrical, hemispheres and solutions that apply geodesic domes to temporary modules. Theirs use is strongly linked to the development of techniques of "nesting" or "pultrusion" that allow the decomposition of the shape of the module, especially the coverage could be divided in a defined number of elements which are finally

Figure 3a: dome houses, the coverage is obtained by assembling super resistant fiberglass panels which guarantee great durability, while the connection between the elements is assigned to a Teflon bolts to lighten the structure. Figure 3b: cylindrical cells normally used for the construction of water pipelines, reused as temporary units

assembled on site. The reinforced polymers can be used also in this case due to their exceptional adaptability to be modeled in curved shapes through an industrial process. The modular unit meets the needs of the con-temporary dwelling whose adaptability and expandability are, on closer inspection, constructively interpreted by the characteristics of the geometry of the basic element: -prefabricated, under a mechanical process (industrial) that allows abatement of production costs and higher quality standards. -lightweight, that means transportable and movable, mostly built with unusual materials, different from cement and steel, such as panels of polymeric materials, -suitable to guarantee a "packing factor" which is as high as possible (to maximize

[1]C. Bovill, "Fractal Geometry as Design Aid", *Journal for Geometry and Graphics, Volume 4, No. 1,* pg 71.

[2]M. J. Ostwald, "Fractal Architecture: late twentieth century connections between architecture and fractal geometry", *Nexus network journal, vol. 3 n.1,* 2001, pg 73.

[3]N. A. Salingaros, conversation with V. Padron. *Ecology and the fractal mind in the New Architecture.* Published by Resource for Urban Design Information (RUDI) on March 2000.

[1]T. Cecere, *L'abitabilità transitoria*, Editore Fiorentino, Napoli, 1984.

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the number of transportable elements), -made with eco-sustainable materials that are easy to recycle with low cost and low environmental impact. Especially using those materials, such as FRPs or organic fiber composites, that ensure a low consumption of "Grey Energy" during the life cycle assessment (LCA) of the building and a consecutive lower emission of CO_2 in the atmosphere, compared to the typical building materials such as steel or concrete. -with an high internal flexibility (quickly changeable to match new needs), -modular (with an high internal flexibility) to ensure the union of several modules as needed.

B. N=n: multiplicity.

Aggregation of modular units becomes the research field in which geometry and architecture meet each other. The aim is identify some criteria that we can follow during the modeling of compouds consisting of several basic elements, in which we can investigate the possibility of union, overlapping and interaction between the individual modules. We hypothesizes the construction of a building as the final result of more elements linked together. "(..) types of artefacts with a variable order or building systems with many degrees of complexity that have the capacity to activate adequate performance under varying conditions of trim, from storage to the use condition, of its constituent elements."[1] Looking to those buildings formed by several parallelepiped or cubic modules we perceive a complex

Figure 4a: aggregations of cubic modules or shipping containers. Their basic geometry allows easy composition into complex shapes that can be instinctively recognized as traditional buildings. Figure 4b: Citè a Docks student housing, Cattani architects, Le Havre, France.

Figure 5a: urban structure designed using shipping containers. Figure 5b: Spugna di Menger, a tridimensional fractal made by an extrusion of the Sierpinski carpet.

volume losing the feel of each module that composes them. The resulting geometry is a sum of basic unit repeated many times, rotated, joined or stacked. The final structure of the aggregate that we obtain is very similar to that of a "normal" building. By extension we can compose the module identified as a building cell, following an "open" aggregative dynamic that produces a n-dimensional built, only repeating its generative units. From one unit (N = 1) to n-units (N = n), from single to multiple, proceeding from the particular to the whole, according to a fractal logic. If we look at three-dimensional developments of linear fractal geometry, such as the Sierpinski carpet, we realize how much is formally similar to those aggregates which can (or could) get by the union of cubic temporary modules in complex construction. It is sur prising, for example, as the form of a group of stacked containers is very similar to the structure of the Menger sponge. This seems suggest that the composition of temporary modules might responds, at least formally, to the criteria of a New Architecture[1], based on the consistency of a fractal logic. An architecture that creates a building that resembles, scaled, to the smallest element that composes it: *"(..) there is some observable structure at every level of magnification, and the different levels of the scale are closely interrelated."*[2]

IV. A PROPONED THEORETICAL VISION

Please note that our proposed vision, is different respect to the current idea of the fractal architecture: the genesis of the development of the units system it isn't, i.e., a generative algorithm but a matrix. In other words we can think at the difference between the concepts of "integral" and "series" (both mathematical concepts). A pre-structured vision of the fractal architecture is totally different from the architecture of the "liquid shape". We don't have a continuity in the building structure, but a "joggle". In fact, the architecture of the generative components generates building, moving from the law of the "dynamic"; our idea, instead, is to understand buildings coming by the law of the "reiteration", of the "sequence". This sequence can repeats itself in different scales, and can move in different directions, generating architectural space (Student House in Utrecht, 2003, by Mart de Jong and De Vijf); in addition, several competition about the prototypes for the housing of the future are based on the same concept too (Living Box prefabricated living unit international competition, 2006) and there are samples where the starting point of the sequence is not the "cell", but the elements of the "cell". ("Modulo", by the Architectural Atelier "a3e" e "in4mal", 2010). The focus is to develop a constructive technology based on self stand frame components on different scale. Certainly an architecture that can express geometrical-fractal buildings is potentially subject to an intense development. Indeed, although it may seem contradictory, an "aggregate" building, which presents a complex volumetric-formal development, it appears, by the perceptive logic of a man, undoubtedly the richest of values comparing to another building, composed of few individual elements. This cognitive dynamic has a more ontological reason than aesthetic: there is a direct connection between the complex structure of object's nature that we observe and, equally complex, the structure of our brains. In substance, exists the possibility that our mind is, by nature, more inclined to find stimulating what it recognizes as geometrically similar.[1]

V. HOUSING FRACTAL ARCHITECTURE

Can we live inside a fractal architecture as easy as we built it? We can assert that because of the very extreme and utopic theories of the avant-garde of the twentieth century

[1]C. Falasca, *Architetture ad assetto variabile*, Alinea Editrice, Firenze,

[1]N. A. Salingaros conversation with V. Padron. "Ecology and the fractal mind in the New Architecture", *Resource for Urban Design Information (RUDI)*, March 2000.

[2]Idem.

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and "Megastructural Architects", we didn't reach a real realization of temporary settlements. Actually the topic is complex, and involves the concept of perception of the built environment and the role that architecture plays in its use. The main problem is related to the shape of living units that, in many cases, creates isolated elements, very different from the topologic concept of a house, and also without an easy and immediate articulation between them. The curved shape, for example, with the exception of the cylinder which can be stacked vertically, constrains to a development of the settlement only in width, by reason of the impossibility of connection (unless additional structures) between the base and the ceiling. In this way the compositive solutions are drastically reduced to a flat distribution of

Figure 6a: spatial distribution of temporary dome houses in a "lager village". Figure 6b: aggregation of shipping containers.

modules, according to an orthogonal grid (the so called "lager typology"), or a chaotic disposition of elements completely disconnected between them. However the opportunity, to use the base module as "brick" to produce complex structural geometries, also creates the possibility to obtain formal geometries, that are the most recognizable and very close to our conception of the city. We believe that the most important difference between different shapes of temporary modules, the factor that distinguishes them from an empathetic point of view, is the potential inherent in their union: the possibility that their composition will generate aggregates that lead to our everyday experience of constructed.

VI. CONCLUSIONS

We believe that the concept of fractal geometry in architecture, starting from a pre-structured cell, may represent an effective response to the current needs of "basic construction"; deeply inserted in the actual architectural debate. Indeed, the research of fractal pre-structured architectures for temporary housing, offers added values which could achieve real benefits from a construction concept, where the architectural form, looks like, scaled, the smallest element that constitutes it. The fractal pre-structured construction has many meanings. It is part of the more topical meaning of the geometric concept of architectural construction, as "complex organism": the formal value of fractal elements represents "de facto", a primary performance requirement for a configuration of the building designed as "resulting effect" of a system and not only as a "sum" of individual elements that compose it. It represents a broad field of inquiry for those designers who wish to rethink man (contemporary/future) and its spaces. In a global scenario, cultural and technical, increasingly large, the concept of home has not reference to stability and permanence.

[1]This would explain why every man finds relaxing and regenerating live in contact with nature and, conversely, a life far from nature is hardly conceivable.

It weighs upon the cultural impact of the concept of architecture itself, in a decisive way, contributing to the idea of *"(..) an architecture that is released from the classic canon of a solid architecture, embedded into the ground and aimed to posterity unchanged and unchangeable."*[1] It represents a challenge which symbolizes all the result of the typological revolution (traditional architecture of architectural types) announced and implemented in architecture by non-traditional geometries. Suggesting to join the quality of permanence of the traditional architecture, the practice of a constant changing through elementary manipulations, additions and replacements of parts. An architecture that can change at one time in which the needs - and then the functions - change over time. Emerge, inside the relationship between the designer and the project, some cognitive implications "subject-object" that remind us that the complex structure of nature is fractal itself *"(..) it is not difficult to concede that our psiche, which has its assumptions built into the brain, has an essentially fractal structure as well."*[1] Would it be rash to claim that architecture and nature can be combined according to a fractal syntax? We know that the "linear" fractal geometrical shapes are attributable to basic geometric shapes: lines, triangles and squares repeated and scaled[2], that create complex structures (linear fractal of Von Coch and Sierpinski). The "nonlinear" fractal geometry, however, (Julia and Mendelbrot algorithms) comes closest to the physical manifestations of nature. *"(..)This type of structure exists in abundance in nature. From the distribution of foliage on a tree, to the complex network of our nervous system; all of these can be better described with the help of Fractal Geometry."*[3] It hinges on the need to manage the containment of energy resources under many aspects: *Make full use of geometric characteristics of modules that foster the possibility to use a wide surface as windows or solar panels, getting, through the holes in facades, a better exposure and permeability, both to the sunlight, and to air recirculation (it may also favour an internal production of wind energy); *Providing easier transportation (and cost reductions) of components (temporary modules) and their relative possibility to be assembled in complex structures; *Permitting, at the end of life cycle, the possibility of recycling materials. It proposes a logical development with other interdisciplinary areas of knowledge, combining, on the one hand, related knowledge: as regards, for example, improving the current characteristics of seismic resistance of homes, using very stable structures due to the rigid interlocking among modules. On the other hand, promoting technology transfer from other areas and experimentation of new materials and techniques (as was already done with the use of shipping containers). It throws (tension inherent in the logic of fractal construction) in the dimension of town-design, which exceeded the limit of the duality between a city as a unique building *"(..) a large-scale urban structure open to the incorporation of individual variations to the architectonic scale"*[1], and a city made up using subsequent individual aggregations.

[1]M. Platania, *Prefazione*, in C. Falasca, *Architetture ad assetto variabile*, Alinea editrice, Firenze, 2000, p.7.

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For these reasons, we believe that further investigations upon the "fractal pre-structured building", could offer an important contribution to contemporary design experimentation, especially in important logical and constructive areas such as mobile and temporary architecture, that today represent an *"ideal conceptual place where we can experiment the construction of the contemporary city's architecture."*[1]

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[2]Recursivity and scaling, used by M. J. Ostwald in his text when he describes the Peter Eisenman's idea about fractal geometry for the design of House 11a. M. J. Ostwald, *Fractal Architecture: late twentieth century connections between architecture and fractal geometry*. Nexus network journal, vol. 3 no1, 2001 pg 74.

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